

Georgia Forestry Commission

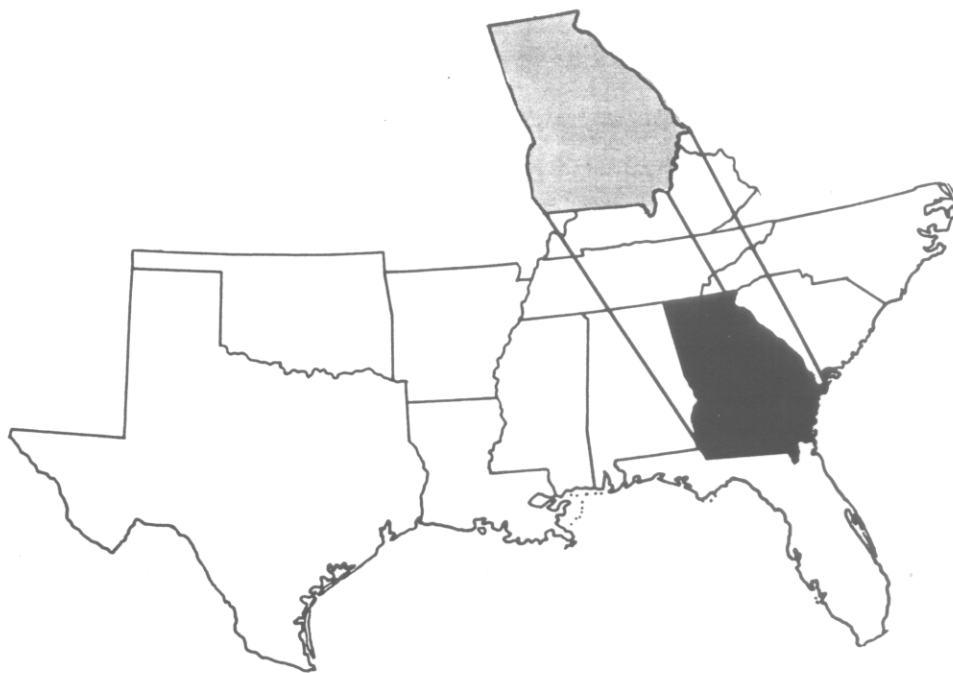
Research **REPORT**

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RELIABILITY OF ESTIMATES BY CRUISE INTENSITY, FOREST CONDITION AND STAND COMPONENT

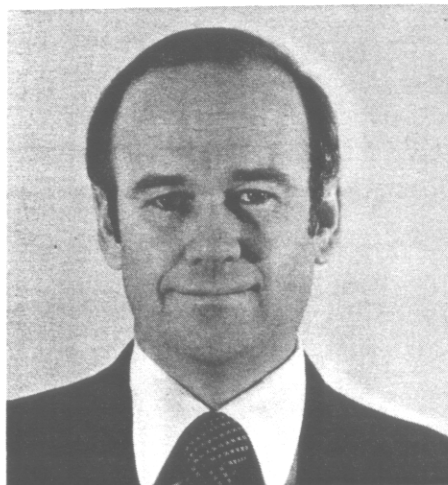
by
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RELIABILITY OF ESTIMATES BY CRUISE INTENSITY, FOREST CONDITION AND STAND COMPONENT

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The reliability of estimates for stand component weights and volumes is affected by the number of cruise plots taken. The required number of sample points for a given level of reliability depends on variability of the specific components to be estimated: this cannot be known without preliminary sampling. In lieu of an actual preliminary cruise, it would be desirable to have a general estimate of cruise reliability based on some easily observed stand characteristics that are related to component variability. Our objective is to present a convenient method for approximating cruise reliabilities for estimates of biomass and merchantable volume in stands of various size classes and proportions of pine and hardwood.

PROCEDURES

Eleven timber stands in the Piedmont and Upper Coastal Plain of Georgia were selected to provide an array of stand conditions (Table 1). Selection criteria were apparent pine-hardwood percentages and proportions in sapling, pulpwood, and sawtimber size classes. All stands were fully stocked and ranged in age from 30 to 70 years. Total woody biomass ranged from about 80 to 111 green tons per acre among the study areas, with hardwoods accounting for 9 to 95 percent of the total weight. Plot centers were located at 150-foot intervals on cruise lines spaced 150 feet apart. Ten-factor prisms were used to select merchantable-size (minimum d.b.h. of 5 inches) sample trees and fixed-radius hundredth-acre tallies were used for smaller stems. Diameters were measured to the nearest inch and heights were estimated to the nearest 5 feet. Species or species groups tallied were pine (*Pinus* sp.), hard hardwood, soft hardwood, oak (*Quercus* sp.), and sweetgum (*Liquidambar styraciflua* L.).

Table 1. -- Location and general stand characteristics for 11 areas in Middle Georgia.

Area	County	BA of all trees		BA of trees >5 inches	
		Pine	Hardwood	Pine	Hardwood
-----ft ² acre-----					
1	Twiggs	55	36	53	27
2	Twiggs	58	44	55	32
3	Twiggs	52	53	46	38
4	Twiggs	82	35	74	18
5	Twiggs	87	5	79	2
6	Jones	33	57	32	33
7	Jones	88	12	85	6
8	Hancock	47	41	45	27
9	Hancock	71	23	67	13
10	Hancock	54	52	44	39
11	Hancock	6	84	5	68

The cruise data were processed by the Total-Tree Multiproduct Cruise Program (Clark and others 1985), with outputs expressed as mean per-acre values in tons, cords, and cunits. The program also provided estimates of stems per acre and basal area per acre by species groups and size classes.

The concept of Stein's two-stage procedure (Steel and Torrie 1960) was applied to the study objective. For variance estimates the study area cruises were treated as first-stage samples from infinite populations with given general stand characteristics. Volume and weight determination was assumed to be without error. Stein's formula for deriving the number of samples needed to estimate a trait in an infinite population with a specified allowable error is:

$$n = t^2_{(n-1)} \frac{cv^2}{p}, \text{ where}$$

n = number of samples required,
 t = Student's t with probability level α ,
 cv = coefficient of variation from the first-stage sample,
 p = specified allowable error.

The unknown element needed to drive the formula is the coefficient of variation. Coefficients of variation were computed by area, species group and stand component (total tree, stem to 4-inch top, sawlog stem) from the cruises in each of the 11 stands. The relationship of coefficients of variation to general stand traits was defined by regression analysis. General stand traits tested were basal area and percentages of basal area in species groups and size classes. The sample sizes needed to estimate specific traits were then computed by reliability levels and stand parameters from the regression-predicted coefficients of variation.

RESULTS AND DISCUSSION

All Species Combined

When the estimated trait was the aggregate biomass of a stand component across all species, there was no significant relationship between coefficients of variation and general stand characteristics. The coefficients of variation based on 10 of the 11 stands exhibited relatively narrow ranges (Table 2).

Table 2. -- Biomass per acre and associated coefficients of variation for all species combined by stand component (based on 10 of 11 stands).

Stand component	Biomass/acre		Coefficient of variation	
	Mean	Range	Mean	Range
	----- tons -----			
All trees ≥ 1 inch	89	81-108	31.9	25.1-36.9
All trees ≥ 5 inches	84	63-104	35.2	26.2-43.0
Stem to 4-inch top	66	49-83	35.6	25.3-46.6
Sawlog stems	32	19-50	56.2	46.5-75.4

The eleventh stand, which was approximately half hardwood and half pine, had coefficients of variation that were substantially larger--67.1 for all trees ≥ 1 inch, 79.6 for trees > 5 inches, 81.2 for stems to a 4-inch top, and 98.2 for sawlogs. This stand exhibited obvious clumping and variation in site quality from place to place.

When cruising natural, fully-stocked stands to estimate component biomass across all species and the trees are evenly distributed, Table 3 can be used to approximate the required number of sample points for a specified allowable error and level of probability. For example, at an allowable error of 15 percent and a 10 percent probability level, approximately 45 cruise plots would be required to estimate the total saw-log weight of all species combined.

Table 3. -- Number of sample points required for a given reliability to estimate component biomass of all species combined.

Probability level α	Allowable error (percent)					
	05	10	15	20	25	30
	-----number of points -----					
	All trees ≥ 1 inch d.b.h.					
.10	135	36	17	10	7	6
.05	194	50	24	14	10	8
	All trees ≥ 5 inches d.b.h.					
.10	169	44	20	12	8	7
.05	240	61	29	17	12	9
	Stem to 4-inch d.o.b. top					
.10	174	45	21	13	9	7
.05	248	63	29	18	12	9
	Sawlog stem					
.10	395	100	45	26	18	13
.05	564	141	64	37	25	18

When clumping and site variability exist within the stand, a preliminary cruise should be conducted to obtain estimated coefficients of variation. Equation 1 can then be used to calculate the number of points required for a given reliability.

SPECIES BREAKDOWN

In estimating stand components by species group, there were significant relationships between coefficients of variation and general stand traits. When operational and statistical considerations were evaluated jointly, the general stand characteristic resulting in the best overall predictors was basal area of trees ≥ 5 inches d.b.h. Basal area of pulpwood-size and larger trees is a stand trait that many foresters and timber cruisers have experience in judging.

Linear regressions of coefficients of variation for the respective pine components on basal area of pine ≥ 5 inches yielded correlation coefficients ranging from 0.88 to 0.93 with plottings of residuals that appeared random. Tables 4 through 7 show the approximate number of sample points required to estimate weight or volume of the respective pine components for a specified allowable error and level of probability as a function of basal area of pine ≥ 5 inches d.b.h. The coefficients and r^2 associated with each table are for the relationship:

$$cv = a + b(BA), \text{ where}$$

cv = estimated coefficient of variation,
BA = basal area of pines ≥ 5 inches d.b.h.

To use the tables, cruisers need the basal area of pines ≥ 5 inches d.b.h. This can be determined by an examination of the stand coupled with previous experience or by using a prism to rapidly estimate the pine basal area at random locations throughout the stand. As an example, Table 4 would be used to approximate the required number of plots for estimating total biomass of all pines ≥ 1 inch d.b.h. If the basal area of pines ≥ 5 inches is 55, the allowable error is 15 percent, and the probability of being outside the specified allowable error is 5 percent, 75 plots would be required. If the cruiser will accept a 10 percent probability of being outside the specified range, only 53 plots would be needed.

Tables 8-11 can be used for hardwood components in the same way that the previous tables are used for pine. The correlation coefficients (r^2) associated with hardwood coefficients of variation are substantially lower than those associated with pine. This is to be expected from the greater variability in branching characteristics and stem form.

Note that the required number of sample points is based on the coefficient of variation and not the acreage over which estimates are desired. Percent sample is an inappropriate guide when point sampling is employed. For a given coefficient of variation the required number of plots should be evenly distributed over the entire stand. Note also that there will be a tendency for the coefficients of variation to increase with acreage because the probability of clumping and poorly-stocked spots increases with area. The cruiser should, therefore, use caution to insure that the guidelines given here are applied only to fully stocked stands. Variable situations call for a return to Equation 1 with actual preliminary cruise data.

Table 4. -- Number of sample points needed to estimate pine total tree biomass for trees ≥ 1 inch based on basal area of pines ≥ 5 inches.

Pine stem basal area	P R O B α	Allowable error (percent)						
		05	10	15	20	25	30	cv ^{1/}
25	.10	1287	327	145	83	54	38	1.090
25	.05	1827	466	207	119	76	54	1.090
30	.10	1119	284	126	72	47	33	1.017
30	.05	1588	405	180	103	66	47	1.017
35	.10	978	244	110	62	41	29	0.943
35	.05	1366	349	155	89	58	41	0.943
40	.10	831	208	94	54	35	25	0.869
40	.05	1161	296	132	76	49	35	0.869
45	.10	696	174	79	45	29	21	0.796
45	.05	993	248	113	63	41	29	0.796
50	.10	573	143	65	38	24	18	0.722
50	.05	817	204	93	53	35	25	0.722
55	.10	462	117	53	30	20	15	0.648
55	.05	659	165	75	43	28	20	0.648
60	.10	363	92	42	24	16	12	0.575
60	.05	518	129	60	34	23	17	0.575
65	.10	276	70	32	19	13	10	0.501
65	.05	393	100	46	27	18	13	0.501
70	.10	201	52	24	14	10	8	0.427
70	.05	286	73	34	20	14	10	0.427
75	.10	137	36	17	10	8	6	0.354
75	.05	196	51	24	15	10	8	0.354
80	.10	87	23	11	7	6	5	0.280
80	.05	123	33	16	10	8	7	0.280
85	.10	48	14	7	6	6	4	0.206
85	.05	68	19	10	7	5	5	0.206

^{1/}cv = 145.86782 - 1.47351 (BA); $r^2 = 0.86$, where cv = coefficient of variation and BA = basal area of pines ≥ 5 inches.

Table 5. -- Number of sample points needed to estimate pine total tree biomass of trees ≥ 5 inches based on basal area of pine ≥ 5 inches.

Pine stem basal area	P R O B α	Allowable error (percent)							$cv^{1/}$
		05	10	15	20	25	30	--	
25	.10	1320	335	149	85	55	39		1.104
25	.05	1875	478	213	122	78	55		1.104
30	.10	1151	292	130	74	48	34		1.031
30	.05	1635	417	185	106	68	48		1.031
35	.10	1010	252	114	64	42	30		0.958
35	.05	1411	360	160	92	60	42		0.958
40	.10	861	215	97	56	36	25		0.885
40	.05	1204	307	137	78	51	36		0.885
45	.10	725	181	82	47	30	22		0.812
45	.05	1013	258	117	66	43	31		0.812
50	.10	600	150	68	39	26	18		0.739
50	.05	856	214	97	56	36	26		0.739
55	.10	487	122	56	32	21	15		0.666
55	.05	695	174	79	45	30	21		0.666
60	.10	386	98	44	26	17	13		0.593
60	.05	551	138	62	37	24	18		0.593
65	.10	297	75	35	20	14	10		0.520
65	.05	423	108	49	28	19	14		0.520
70	.10	219	57	26	15	11	8		0.446
70	.05	312	80	37	22	15	11		0.446
75	.10	153	40	19	11	8	6		0.373
75	.05	218	57	26	16	11	9		0.373
80	.10	101	26	13	8	7	6		0.300
80	.05	141	38	18	11	8	7		0.300
85	.10	58	16	8	6	5	5		0.227
85	.05	82	22	11	8	6	6		0.227

$\frac{1}{cv} = 147.00890 - 1.46243(BA); r^2 = 0.82$, where cv = coefficient of variation and BA = basal area of pines ≥ 5 inches.

Table 6. -- Number of sample points needed to estimate pine stem weight or volume to a 4-inch top based on basal area of pine ≥ 5 inches.

Pine stem basal area	P R O B α	Allowable error (percent)						
		05	10	15	20	25	30	$cv^{1/}$
25	.10	1315	334	148	85	55	39	1.102
25	.05	1866	476	212	121	78	55	1.102
30	.10	1146	291	129	74	48	34	1.029
30	.05	1628	415	185	106	68	48	1.029
35	.10	1006	251	113	64	41	29	0.956
35	.05	1405	359	159	91	60	42	0.956
40	.10	858	215	97	55	36	25	0.883
40	.05	1199	306	136	78	51	36	0.883
45	.10	722	181	82	47	30	22	0.811
45	.05	1010	258	117	66	43	31	0.811
50	.10	598	150	68	39	25	18	0.738
50	.05	853	213	97	56	36	26	0.738
55	.10	486	122	56	32	21	15	0.665
55	.05	693	173	79	45	30	21	0.665
60	.10	385	98	44	26	17	13	0.592
60	.05	550	137	62	37	24	18	0.592
65	.10	296	75	34	20	14	10	0.519
65	.05	423	108	49	28	19	14	0.519
70	.10	219	56	26	15	11	8	0.446
70	.05	312	80	37	22	15	11	0.446
75	.10	153	40	19	11	8	6	0.373
75	.05	219	57	26	16	11	9	0.373
80	.10	101	26	13	8	7	6	0.301
80	.05	142	38	18	11	8	7	0.301
85	.10	59	16	8	6	5	5	0.228
85	.05	83	22	11	8	6	6	0.228

$\frac{1}{cv} = 146.63124 - 1.45718(BA); r^2 = 0.82$, where cv = coefficient of variation and BA = basal area of pines ≥ 5 inches.

Table 7. -- Number of sample points needed to estimate pine sawlog stem weight or volume based on basal area of pine ≥ 5 inches.

Pine stem basal area	P R O B α	Allowable error (percent)						$cv \frac{1}{\underline{\quad}}$
		05	10	15	20	25	30	
25	.10	2055	522	232	130	85	60	1.378
25	.05	2918	744	331	186	122	84	1.378
30	.10	1789	454	202	115	74	52	1.286
30	.05	2540	648	288	162	106	73	1.286
35	.10	1541	391	174	99	64	45	1.193
35	.05	2188	558	248	140	91	63	1.193
40	.10	1312	333	148	85	55	39	1.101
40	.05	1862	475	211	121	78	55	1.101
45	.10	1101	280	124	71	46	33	1.008
45	.05	1563	399	177	102	65	46	1.008
50	.10	923	231	104	59	39	27	0.916
50	.05	1289	329	146	84	55	39	0.916
55	.10	746	187	84	48	31	22	0.824
55	.05	1043	266	121	68	44	31	0.824
60	.10	588	147	66	39	25	18	0.731
60	.05	839	210	95	55	36	25	0.731
65	.10	449	114	51	30	20	14	0.639
65	.05	640	160	73	42	28	20	0.639
70	.10	328	83	38	22	15	11	0.547
70	.05	468	119	54	31	21	15	0.547
75	.10	227	58	27	16	11	8	0.454
75	.05	323	83	38	22	15	11	0.454
80	.10	144	38	18	11	8	7	0.362
80	.05	205	53	25	15	11	8	0.362
85	.10	81	22	11	7	5	4	0.269
85	.05	116	30	15	10	8	6	0.269

$\frac{1}{\underline{\quad}}_{cv} = 183.98396 - 1.84756(BA); r^2 = 0.77$, where cv = coefficient of variation and BA = basal area of pines ≥ 5 inches.

Table 8. -- Number of sample points needed to estimate biomass of all hardwoods ≥ 1 inch based on basal area of hardwoods ≥ 5 inches.

Pine stem basal area	P R O B α	Allowable error (percent)						$cv^{1/}$
		05	10	15	20	25	30	
25	.10	1013	253	114	64	42	30	0.960
25	.05	1416	361	161	92	60	42	0.960
30	.10	858	215	97	55	36	25	0.883
30	.05	1199	306	136	78	51	36	0.883
35	.10	716	179	81	46	30	22	0.807
35	.05	1021	255	116	65	43	30	0.807
40	.10	587	147	66	38	25	18	0.730
40	.05	837	209	95	54	36	25	0.730
45	.10	470	119	54	31	20	15	0.654
45	.05	670	168	76	44	29	21	0.654
50	.10	367	93	42	24	16	12	0.577
50	.05	523	131	61	35	23	17	0.577
55	.10	276	70	32	19	13	10	0.501
55	.05	393	100	46	27	18	13	0.501
60	.10	198	51	24	14	10	8	0.424
60	.05	282	72	33	20	14	10	0.424
65	.10	133	35	17	10	7	6	0.348
65	.05	190	49	23	14	10	8	0.348

$\frac{1}{cv} = 134.24665 - 1.53018(BA); r^2 = 0.56$, where cv = coefficient of variation and BA = basal area of hardwoods ≥ 5 inches.

Table 9. -- Number of sample points needed to estimate biomass of all hardwoods ≥ 5 inches based on basal area of hardwoods ≥ 5 inches.

Hardwood stem basal area	P R O B α	Allowable error (percent)						$cv^{-1/}$
		05	10	15	20	25	30	
25	.10	1458	370	165	94	61	42	1.160
25	.05	2069	528	235	132	86	61	1.160
30	.10	1228	312	139	79	51	36	1.065
30	.05	1743	445	198	113	73	51	1.065
35	.10	1017	258	117	66	43	30	0.969
35	.05	1444	368	164	94	61	43	0.969
40	.10	840	210	95	54	35	25	0.874
40	.05	1173	299	133	76	50	35	0.874
45	.10	666	166	75	43	28	20	0.778
45	.05	950	237	108	62	40	28	0.778
50	.10	512	128	59	34	22	16	0.683
50	.05	731	183	83	48	31	22	0.683
55	.10	379	96	43	25	17	12	0.587
55	.05	541	135	61	36	24	17	0.587
60	.10	266	67	31	18	12	9	0.492
60	.05	379	97	44	26	17	13	0.492
65	.10	172	44	21	13	9	7	0.396
65	.05	246	63	29	18	12	9	0.396

$\frac{1}{cv} = 163.82729 - 1.91115(BA); r^2 = 0.64$, where cv = coefficient of variation and BA = basal area of hardwoods ≥ 5 inches.

Table 10. -- Number of sample points needed to estimate hardwood stem weight or volume to a 4-inch top based on basal area of hardwoods ≥ 5 inches.

Hardwood stem basal area	P R O B α	Allowable error (percent)						
		05	10	15	20	25	30	cv ^{1/}
25	.10	1459	371	165	94	61	42	1.161
25	.05	2071	528	235	132	86	61	1.161
30	.10	1242	315	140	80	52	37	1.071
30	.05	1763	450	200	115	73	52	1.071
35	.10	1042	265	119	67	44	31	0.981
35	.05	1479	377	168	96	62	44	0.981
40	.10	873	218	99	56	37	26	0.891
40	.05	1220	311	138	79	52	37	0.891
45	.10	705	176	80	45	30	21	0.801
45	.05	1006	251	114	64	42	30	0.801
50	.10	556	139	63	36	24	17	0.711
50	.05	793	198	90	52	34	24	0.711
55	.10	424	108	49	28	19	14	0.621
55	.05	605	151	69	40	26	19	0.621
60	.10	310	79	36	21	14	11	0.531
60	.05	442	113	51	30	20	15	0.531
65	.10	214	55	25	15	10	8	0.441
65	.05	305	78	36	21	15	11	0.441

^{1/}cv = 161.11720 - 1.80053(BA); $r^2 = 0.60$, where cv = coefficient of variation and BA = basal area of hardwoods ≥ 5 inches.

Table 11. -- Number of sample points needed to estimate hardwood sawlog stem weight or volume based on basal area of hardwoods ≥ 5 inches.

Hardwood stem basal area	P R O B α	Allowable error (percent)						cv ^{1/}
		05	10	15	20	25	30	
25	.10	4164	1041	470	264	169	119	1.961
25	.05	5911	1478	670	377	241	168	1.961
30	.10	3362	854	379	213	137	96	1.762
30	.05	4773	1193	541	304	195	135	1.762
35	.10	2646	672	299	168	109	76	1.563
35	.05	3756	958	426	240	153	109	1.563
40	.10	2015	512	227	128	83	59	1.365
40	.05	2861	730	324	182	119	83	1.365
45	.10	1471	373	166	95	62	43	1.166
45	.05	2088	533	237	133	87	62	1.166
50	.10	1012	257	116	65	42	30	0.967
50	.05	1436	366	163	93	61	42	0.967
55	.10	648	162	73	42	27	20	0.768
55	.05	924	231	105	60	39	28	0.768
60	.10	356	90	41	24	16	12	0.569
60	.05	507	127	59	34	22	16	0.569
65	.10	150	39	18	11	8	6	0.370
65	.05	215	56	26	16	11	9	0.370

^{1/}cv = 295.58755 - 3.97835(BA); r² = 0.54, where cv = coefficient of variation and BA = basal area of hardwoods ≥ 5 inches.

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